VEHICLE EMISSIONS AT INTERSECTIONS BEFORE AND AFTER SIGNAL IMPROVEMENT: ZONGULDAK EXAMPLE

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Abstract: Emissions of motor vehicles, one of the most important air pollution sources in the city, are emerging as a growing problem in large-scale cities. The amounts of emissions are affected by the number of vehicles in traffic, vehicle technology, geometric and traffic conditions of highways and intersections, environmental factors and driver behaviors. Traffic flow is mostly interrupted at Intersections in local traffic especially at city centers. Emissions of these points, where traffic behavior is changed and vehicles stop and go, are higher as compared to uninterrupted flows.In this study, current state emissions at Zonguldak Intercity Bus Terminal Intersection were determined by SIDRA INTERSECTION software. Then, new emissions are determined by the same software after improvement in signalization.As a result of the study, fuel consumption and pollutant emissions were calculated before and after improvement. As a result of observations at the intersection, current state fuel consumption was calculated as 477.2 l/hour and CO_2, CO, HC and NOx emissions were 1229.0, 0.806, 0.126 and 1.212 kg/hour respectively for morning. Then, intersection was modeled again after improvement by changing the cycle time. This leads to 48% reduction in total fuel consumption. In addition, CO_2, CO, HC and NOx emissions were reduced by 48%, 56%, 61% and 42% respectively. After that current state fuel consumption was calculated as 545.8 l/hour and CO_2, CO, HC and NOx emissions were 1289.1, 0.917, 0.147 and 1.154 kg/hour respectively for the evening. Then, intersection was modeled again after improvement by changing the cycle time. This leads to 45% reduction in total fuel consumption. In addition, CO_2, CO, HC and NOx emissions were reduced by 45%, 54%, 57% and 42% respectively. It has been determined that there were significant differences between current state and after improvement. Improvements on geometric conditions or signalization at intersections may result in decrease in vehicle emissions and improving air quality of cities.

Keywords: Air Pollution, Motor Vehicle Emissions, SIDRA INTERSECTION, Turkey.

I. INTRODUCTION

The transport sector is one of the most important contributors with an impact of about 16% on greenhouse gas emissions (Yanarocak 2007).Emissions of motor vehicles, one of the most important sources of urban air pollution, are emerging as a growing problem, especially in urban centers. Emissions of carbon monoxide (CO), hydrocarbons (HC), nitrogen oxides (NOx) and carbon dioxide (CO_2) have significant contributions to air pollution in city centers. In these areas, pollutant emissions are higher due to human activities and traffic intensity.
There are many factors that affect traffic-related emissions. These factors include the number of vehicles in traffic, vehicle technology, and road and intersection geometry, signalization of intersections, environmental factors and driver behavior.

Carbon dioxide emissions are the highest pollution that emerges from transport sector. This emission is released to the atmosphere as a result of combustion of petroleum-based products such as gasoline and diesel in internal combustion engines. The release of methane (CH_4) and nitrogen oxides (NOx) are relatively lower during combustion of the fuel. The major source of greenhouse gas emissions related to transportation is automobiles and trucks because of the large number of vehicles. These sources constitute more than half of the emissions in the sector (USEPA, 2017).
Road and street intersections force vehicular traffic to slow down and stop. The longer the stops, more fuel are consumed and thevehicular emissions increase. Along with the ever-increasing vehicle emissions, it has become important to identify effective traffic control methods to improve traffic flow and reduce emissions per vehicle kilometer (Mandavilli et al., 2003).
A study by Hydén and Várhelyi (2000) at small roundabouts-as speed reducing measures-was carried out in a Swedish. The time consumption at a time operated signal was reduced heavily by the instalment of a roundabout at a signalized intersection. Emissions (CO and NOx) at roundabouts replacing non-signalized intersection increased by between 4 and 6%, while a roundabout replacing a signalized intersection led to a reduction by between 20 and 29%.
Mandavilli et al. (2003), conducted a study at three locations in Kansas, where a modern roundabout has replaced a stop controlled intersection. HC, CO, NOX, and CO_2 in (kg/hr.) were chosen as air pollution indicators. They stated that carbon monoxide (CO) was reduced by 45%, carbon dioxide by 61%, nitrogen oxides (NOx) by 51%, and hydrocarbons (HC) by 68%. It was found that the modern roundabout performed better than the existing

intersection control (i.e. stop signs) in cutting down vehicular emissions, thereby resulting in a positive impact on the environment.

II. DETAILS EXPERIMENTAL

2.1. Materials and Procedures

2.1.1 Study Area

The study was conducted in Zonguldak/Turkey which is a small city that has high traffic intensity. It is known that the number of vehicles in Zonguldak has increased by 21% in the last 5 years. As a result it was concluded that one of the main sources of air pollution in city center includes traffic related emissions. In this context, determination of traffic emissions' contribution to air quality, especially at intersections, is importance in terms of taking proper precautions.

The study was conducted at the 100th Year Intercity Bus Terminal Intersection which is located on state road D010.At the intersection with high traffic load, especially at peak times, travel times increase and vehicles queue. As a result, vehicle emissions are increasing considerably. The intersection is subject to considerable traffic volume due to intercity buses coming from the terminal, urban vehicle traffic and heavy vehicles such as trucks and trailers.

A view from the air of the intersection is given in Figure 1 and geometric view is given in Figure 2. As can be seen from Fig. 1 and 2, the intersection has 5 sites. All the sites were controlled by stop signs on all approaches without for the number 5. The lane width changes between 3.30-3.40 meters without number 2. Terminal approach widths are 4.6 and 8.6 meters.

Fig.1. Zonguldak 100th Year Intercity Bus Terminal Intersection view from the air.

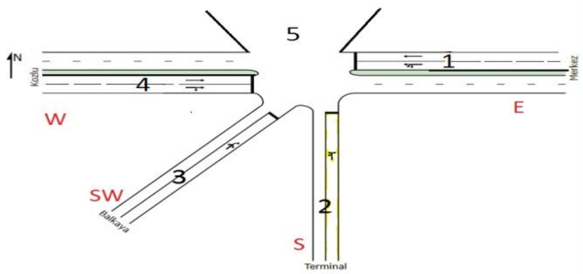

Fig.2. Zonguldak 100th Year Intercity Bus Terminal Intersection geometric view.

The approaches 1 and 4 have two lanes. In these approaches, vehicle queues are formed in the present signalization, especially for straight-going vehicles. Approach 2 provides entry and exit of vehicles into the bus terminal and consists of two lanes. Approach 3 is also consists of two lanes straight and return.Approach 5 is used for short-term parking of vehicles.

2.1.2. Traffic Volumes

Firstly video camera was recorded at the intersection to determine the traffic volume. And then traffic counts were obtained visually from records. Video recording was performed between 08:00-09:00 in the morning and 18:00-19:00 in the evening and vehicle volumes were determined for each lane. The volumes were entered at SIDRA for modelling.

Traffic volumes in the morning and at the evening for all approaches 1, 2, 3, 4 and 5 are given in Table 1.

Table 1. Traffic volumes at Terminal intersection in the morning and evening hours.

Approach No	Morning (07:00-08:00)		Evening (18:00-19:00)	
	L.V.	H.V.	L.V.	H.V.
1	1021	31	1192	22
2	10	5	31	2
3	267	2	213	0
4	713	34	742	27
5	8	0	17	0
Total	2019	72	2195	51

*L.V: Light vehicle, H.V: Heavy vehicle.

As can be seen from the table, in the morning hours, total hourly volumes at approach one are 1021 L.V and 31 H.V, approach two are 10 L.V and 5 H.V, approach three are 267 L.V and 2 H.V, approach four are 713 L.V and 34 H.V, approach five are 8 L.V and 0 H.V.

Total hourly volumes in the evening are; 1192 L.V and 22 H.V at approach one, 31 L.V and 2 H.V at approach two, 213 L.V and 0 H.V at approachthree,742 L.V and 27 H.V at approach four and 17 L.V and 0 H.V at approach five.

The results of the morning and evening observations show that, light and heavy vehicle volumes of the approaches 1 and 4 have the highest volume when compared to other approaches. Approach 3 has also high volume. As expected, approach 2 and 5 volumes are fewer. The reason of the lower volume at approach 2 is its use for to enter and exit from the Terminal. Approach 5 is also used by the vehicles for short time parking.

2.1.3. Modelling of Terminal Intersection

There are a number of parameters that must be entered in the program for the modeling. These are; intersection geometry, traffic data and signaling data.These data were obtained from studies conducted at the field andtheywere entered to the program for the morning and the evening along with volumes. The phase diagram of the current situation and the cycle time (100 sec) were also entered.Thus the current situation analysis of the intersection was completed. Then a new cycle period was determined. This period was determined as 120 secondsby the SIDRA. A new analysis was carried out with the new cycle time for the morning and the evening hours, as all other data remaining the same.By changing the cycle time it was aimed to improve intersection.The emission values obtained for two different analyzes were compared.

2.1.4. Traffic Emission

Within the framework of national greenhouse gas emissions inventory studies, the use of energy, industrial processes, solvents and other products, agricultural activities and waste emissions can be calculated using the approaches recommended in the International Climate Change Panel (IPCC) Guidelines (TÜİK, 2011).According to the IPCC Implementation Guidelines (GPG, 2000); the emission sources are considered as a key sources of a country which contributes 95% of the total emissions as CO_2 equivalents.

The transport sector is one of the key sources mentioned in these guidelines and is under the heading of the energy sector. Transport sector include highway, railway, domestic civil aviation and national maritime activities. The application guide offers three different formulas for calculating emissions namely Tier 1, Tier 2 and Tier 3. The selection of the formula is based on the amount of data available (EMEP/EEA, 2016). Emission factors to be used in calculations can be obtained directly from the EMEP/EEA Emission Inventory Guide published by the European Environment Agency. The conventional method of preparing emission inventory is to multiply the emission factors by the activity statistics and the number of vehicles. In this study, emissions were calculated by using SIDRA software instead of the conventional method.

SIDRA is a microsimulation model for realistic assessment of road traffic conditions using in-traffic vehicle data or user defined drive cycles. It uses a power based vehicle model to estimate fuel consumptions and emissions of carbon dioxide (CO_2), carbon monoxide (CO), hydrocarbons (HC) and nitrogen oxides (NOx). It is ideal to compare traffic and travel conditions before and after intersection and road improvements (Akçelik, 2011).

SIDRA Intersection software classifies vehicles as “light duty” and “heavy duty” when performing fuel consumptionand emission calculations. Heavy duty vehicles have more than two axles or have dual tires on rear axle (in other words vehicle with more than four tires). All other vehicles like automobiles, vans and small trucks are considered as light duty vehicles. Fuel consumptions and emissions at the intersections are calculated for standard driving cycle which consists of cruise, deceleration, idling and acceleration. Fuel consumption at an instantaneous time is the function of tractive power (Eq. 1-6) (Akçelik et al., 2012).

Instantaneous fuel consumption rates (mL/s) can be calculated by the following model;

$$f_t = \alpha + \beta_1 R_T v + [\beta_2 M_v a P_I]a>0 \qquad P_T > 0 \qquad (1)$$
$$f_t = \alpha \qquad P_T < 0$$
$$P_T = \min(P_{max}, P_C + P_I + P_G) \qquad (2)$$
$$P_C = b_1 v + b_2 v^3 \qquad (3)$$
$$P_I = M_v a v / 1000 \qquad (4)$$
$$P_G = 9.81 M_v (G / 100) v / 1000 \qquad (5)$$
$$\alpha = f_i / 3600 \qquad (6)$$

Where,

f_t : Instantaneous fuel consumption rate (mL/s),
P_T : Total tractive power (kilowatt, kW),
P_{max} : Maximum engine power (kW),
P_C : Cruise component of total power (kW),
P_I : Inertia component of total power (kW),
P_G : Grade component of total power (kW),
G : Road grade (per cent), negative if downhill,
M_v : Vehicle mass (kg) including occupants and any other load,
v : Instantaneous speed (m/s) = v (km/h)/3.6
a : Instantaneous acceleration rate (m/s^2), negative for deceleration,
α : Constant idle fuel consumption rate (mL/s),
f_i= 3600α: constant idle fuel consumption rate (mL/h),
b_1 : Vehicle parameter related mainly to the rolling resistance (kN),
b_2 : Vehicle parameter related mainly to the aerodynamic drag ($kN/(m/s)^2$),
β_1 : The efficiency parameter which relates fuel consumed to the total power provided by the engine (mL/kJ or g/kJ),

β_2 : The efficiency parameter which relates fuel consumed during positive acceleration to the product of acceleration rate and inertia power ($mL/(kJ.m/s^2)$ or $g/(kJ.m/s^2)$).

On a level road (G=0, PG=0), the instantaneous cruise fuel consumption rate (a=0, PI=0) is calculated by using following equations (7a, 7b, 7c, 8a and 8b):

$$f_{ct} = \alpha + \beta_1 P_C \qquad (7a)$$
$$f_{ct} = \alpha + \beta_1 (b_1 v + b_2 v^3) \qquad (7b)$$
$$f_{ct} = \alpha + c_1 v + c_2 v^3 \qquad (7c)$$

Where;

$$c_1 = b_1\beta_1 \qquad (8a)$$
$$c_2 = b_2\beta_1 \qquad (8b)$$

The unit of c_1 parameter is mL/m and the unit of c_2 parameter is $(mL/m) / (m/s)^2$.

Equation 7c is used in model calibration for fuel consumption. After calibration, the values of c_1, c_2

and β_1 are determined. Then, the inputs of the model (A and B parameters) are calculated by using following equations (Eq. 9a, 9b).

$$A = 1000\ c_1 \quad (9a)$$

$$B = c_2 / 0.01296 \quad (9b)$$

Where, the unit of A parameter is mL/km and the unit of B parameter is $(mL/km)/(km/h)^2$.

b_1 and b_2 parameters are calculated indirectly by Equations 10a and 10b.

$$b_1 = c_1 / \beta_1 \quad \text{if } \beta_1 > 0 \quad (10a)$$

$$b_1 = 0 \quad \text{if } \beta_1 = 0$$

$$b_2 = c_2 / \beta_1 \quad \text{if } \beta_1 > 0 \quad (10b)$$

$$b_2 = 0 \quad \text{if } \beta_1 = 0$$

The purpose of using c_1 and c_2 in Eq. 10a and 10b is to obtain a reasonable representation of drag power provided by engine in fuel consumption.

The instantaneous carbon dioxide (CO_2) emission (g/s) is directly estimated by using the instantaneous fuel consumption rate (Eq. 11).

$$f_t(CO_2) = f_{CO2} f_t(fuel) \quad (11)$$

Where,

ft(fuel) : fuel consumption rate (mL/s),

f_{CO2}: CO_2 to fuel consumption rate (g/mL) or (kg/L).

Model estimates carbon monoxide (CO), hydrocarbons (HC) and nitrogen oxides (NOx) emission rates (mg/s) by using the same procedure with different parameters (Akçelik et al., 2012). These parameters are given in Table 2for light duty vehiclesand Table 3for heavy duty vehicles respectively.

Table 2. SIDRA INTERSECTION fuel consumption and emission model parameters (light duty vehicle).

*	Fuel	CO	HC	NOx
Idling rate, f_i	1200.0	1620.0	340.0	300.0
Drag parameter, A	16.0	-138.0	-9.0	-14.0
Drag parameter, B	0.004	0.0743	0.0031	0.0068
Efficiency parameter, β	0.1	0.294	0.029	0.166

*Mass: 1600 kg, Max power: 120 kW, CO_2 to fuel consumption rate: 2.35

Table 3. SIDRA INTERSECTION fuel consumption and emission model parameters (heavy duty vehicle).

*	Fuel	CO	HC	NOx
Idling rate, f_i	2300.0	25000.0	3000.0	44000.0
Drag parameter, A	200.0	-320.0	1.0	2820.0
Drag parameter, B	0.009	-0.06	-0.0016	0.21
Efficiency parameter, β	0.075	0.04	0.0013	1.9

*Mass: 15000 kg, Max power: 170kW, $CO_2$to fuel consumption rate: 2.63

III. RESULTS

As a result of the observations, firstly the current situation of intersection was modeled with SIDRA then total fuel consumptions and carbon dioxide, carbon monoxide, hydrocarbons, and nitrogen oxide emissions were calculated. After that, the same parameters were calculated with the new cycle time. Total fuel consumptions and air pollutant emissions for the morning and evening hours are given in Table 4 and Table 5.

Table 4. Calculated fuel consumptions and emissions for the morning.

Emissions	Fuel (lt/h)	CO_2 (kg/h)	CO (kg/h)	HC (kg/h)	NOx (kg/h)
Current situation (100 sec)	477.20	1129.00	0.806	0.126	1.212
After improvement (120 sec)	248.50	589.50	0.352	0.049	0.706
Difference	228.70	539.50	0.454	0.077	0.506
Difference (%)	48	48	56	61	42

Table 5. Calculated fuel consumptions and emissions for the evening.

Emissions	Fuel (lt/h)	CO_2 (kg/h)	CO (kg/h)	HC (kg/h)	NOx (kg/h)
Current situation (100 sec)	545.8	1289.1	0.917	0.147	1.154
After improvement (120 sec)	297.9	704.2	0.423	0.063	0.667
Difference	247.90	584.9	0.494	0.084	0.49
Difference (%)	45	45	54	57	42

Vehicle emissions are mostly related to fuel consumptions. For that reason, when we have a look at the fuel consumption rates, one can see that, fuel consumptions are reduced significantly after changing cycle time both for the morning and evening hours.

As can be seen from Table 4, in the morning hours, the fuel consumption rate was 477.2 l/h for the current situation and decreases to 248.5 l/h after changing cycle time. In relation to reduced consumption rates, the emissions of CO_2, CO, HC and NOx decreases by 48, 56, 61 and 42% after improvement.

In the evening, fuel consumption and emission rates, given in Table 5, also decrease. Fuel consumption rate was calculated as 545.8 l/h and decreases to 297.9 l/h before and after improvement. The emissions of air pollutants were decreased by 45, 54, 57 and 42% for CO_2, CO, HC and NOx.

When the morning and evening fuel consumptions rates and emissions were compared, it could be seen that, evening results are higher than morning results for all parameters. This is due to higher volumes in the evening hours. Moreover, vehicles start and stop,

results in higher fuel consumption rates and higher emissions.
Approximately 230-250 l/h of fuel savings resulting from the signalization improvement is a very significant achievement. On May 11 2018, the price of gasoline in Zonguldak Center is 1.16EUR/l and the price of diesel is 1.06 EUR/l. If the average fuel price is assumed as 1.10EUR and at the intersection volume of vehicle traffic is considered as the same for 8 hours a day, the total fuel cost to be saved per year can be calculated as approximately 770880 EUR (240 l/h × 1.10 EUR/l× 8h/day× 365 days).
Future research on emission calculations based on signalization improvement, are very important in terms of environmental and economic considerations.

IV. DISCUSSION AND CONCLUSIONS

SIDRA INTERSECTION software was developed primarily for use by experts working in the field of traffic engineering. The software is continuously updated to meet the requirements. In terms of environmental engineering, the most important of these updates was the calculation of the fuel consumption and emissions.

The most outstanding result in our study was that, the signalization improvements at the intersections have reduced the amount of emissions significantly. SIDRA is one of the most important software in the world used to obtain reliable data in such studies. Furthermore, it can be said that this software is more advantageous than the conventional calculation methods to prepare emission inventory. In the conventional method, the road type is selected as urban, rural or highway and it is assumed that vehicles travel at a constant speed. In SIDRA, vehicles are not assumed to be at a constant speed, otherwise slowdown and stop-and-start movements are also taken into consideration. Hence, the emissions calculated by this software are thought to be more sensitive. The values obtained by the software can be compared with field studies to make a better evaluation. Therefore, further studies will be conducted on field sampling at the terminal intersection. With the increase of these kind of studies, the default parameters used in the program (fi, A, B, β) can be changed by new parameters determined nationally.

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